Image correlation pattern optimization for micro-scale in-situ strain measurements

G.F. Bomarito and J.D. Hochhalter

NASA Langley Research Center, Durability, Damage Tolerance, and Reliability Branch, Hampton, VA, USA.

A.H. Cannon

1900 Engineering, LLC, Clemson, SC, USA

March 4, 2016

Extended Abstract

The accuracy and precision of digital image correlation (DIC) is a function of three primary ingredients: image acquisition, image analysis, and the subject of the image. Development of the first two (i.e. image acquisition techniques and image correlation algorithms) has led to widespread use of DIC; however, fewer developments have been focused on the third ingredient. Typically, subjects of DIC images are mechanical specimens with either a natural surface pattern or a pattern applied to the surface. Research in the area of DIC patterns has primarily been aimed at identifying which surface patterns are best suited for DIC, by comparing patterns to each other. Because the easiest and most widespread methods of applying patterns have a high degree of randomness associated with them (e.g., airbrush, spray paint, particle decoration, etc.), less effort has been spent on exact construction of ideal patterns. With the development of patterning techniques such as microstamping [1] and lithography, patterns can be applied to a specimen pixel by pixel from a patterned image. In these cases, especially because the patterns are reused many times, an optimal pattern is sought such that error introduced into DIC from the pattern is minimized.

DIC consists of tracking the motion of an array of nodes from a reference image to a deformed image. Every pixel in the images has an associated intensity (grayscale) value, with discretization depending on the bit depth of the image. Because individual pixel matching by intensity value yields a non-unique scale-dependent problem, subsets around

each node are used for identification. A correlation criteria is used to find the best match of a particular subset of a reference image within a deformed image. The reader is referred to references [2–4] for enumerations of typical correlation criteria.

As illustrated by Schreier and Sutton [5] and Lu and Cary [6] systematic errors can be introduced by representing the underlying deformation with under-matched shape functions. An important implication, as discussed by Sutton et al. [4], is that in the presence of highly localized deformations (e.g., crack fronts), error can be reduced by minimizing the subset size. In other words, smaller subsets allow the more accurate resolution of localized deformations. Contrarily, the choice of optimal subset size has been widely studied [7–12] and a general consensus is that larger subsets with more information content are less prone to random error. Thus, an optimal subset size balances the systematic error from under matched deformations with random error from measurement noise [10].

The alternative approach pursued in the current work is to choose a small subset size and optimize the information content within (i.e., optimizing an applied DIC pattern), rather than finding an optimal subset size. In the literature, many pattern quality metrics have been proposed, e.g., sum of square intensity gradient (SSSIG) [13], mean subset fluctuation [14], gray level co-occurrence [8], autocorrelation-based metrics [7, 15, 16], and speckle-based metrics [12, 17]. The majority of these metrics were developed to quantify the quality of common pseudo-random patterns after they have been applied, and were not created with the intent of pattern generation. As such, it is found that none of the metrics examined in this study are fit to be the objective function of a pattern generation optimization. In some cases, such as with speckle-based metrics, application to pixel by pixel patterns is ill-conditioned and requires somewhat arbitrary extensions. In other cases, such as with the SSSIG, it is shown that trivial solutions exist for the optimum of the metric which are ill-suited for DIC (such as a checkerboard pattern).

In the current work, a multi-metric optimization method is proposed whereby quality is viewed as a combination of individual quality metrics. Specifically, SSSIG and two auto-correlation metrics are used which have generally competitive objectives. Thus, each metric could be viewed as a constraint imposed upon the others, thereby precluding the achievement of their trivial solutions. In this way, optimization produces a pattern which balances the benefits of multiple quality metrics. The resulting pattern, along with randomly generated patterns, is subjected to numerical deformations and analyzed with DIC software. The optimal pattern is shown to outperform randomly generated patterns.

References

[1] AH Cannon, JD Hochhalter, AW Mello, GF Bomarito, and MD Sangid. Microstamping for improved speckle patterns to enable digital image correlation. *Microscopy and Microanalysis*, 21(S3):451–452, 2015.

[2] B Pan, K Qian, H Xie, and A Asundi. Two-dimensional digital image correlation for

in-plane displacement and strain measurement: a review. *Measurement Science and Technology*, 20(6):062001, 2009.

[3] B Pan. Recent progress in digital image correlation. *Experimental Mechanics*, 51(7): 1223–1235, 2011.

[4] MA Sutton, JJ Orteu, and H Schreier. *Image correlation for shape, motion and deformation measurements: basic concepts, theory and applications.* Springer Science & Business Media, 2009.

[5] HW Schreier and MA Sutton. Systematic errors in digital image correlation due to undermatched subset shape functions. *Experimental Mechanics*, 42(3):303–310, 2002.

[6] H Lu and PD Cary. Deformation measurements by digital image correlation: implementation of a second-order displacement gradient. *Experimental Mechanics*, 40(4): 393–400, 2000.

[7] K Triconnet, K Derrien, F Hild, and D Baptiste. Parameter choice for optimized digital image correlation. *Optics and Lasers in Engineering*, 47(6):728–737, 2009.

[8] C Lane, RL Burguete, and A Shterenlikht. An objective criterion for the selection of an optimum dic pattern and subset size. *Proceedings of the XIth International Congress and Exposition*, pages 1–9, 2008.

[9] B Pan, H Xie, Z Wang, K Qian, and Z Wang. Study on subset size selection in digital image correlation for speckle patterns. *Optics Express*, 16(10):7037–7048, 2008.

[10] Y Sun and JH Pang. Study of optimal subset size in digital image correlation of speckle pattern images. *Optics and Lasers in Engineering*, 45(9):967–974, 2007.

[11] D Lecompte, S Bossuyt, S Cooreman, H Sol, and J Vantomme. Study and generation of optimal speckle patterns for dic. *Proceedings of the Annual Conference and Exposition on Experimental and Applied Mechanics*, 3:1643–1649, 2007.

[12] D Lecompte, A Smits, S Bossuyt, H Sol, J Vantomme, D Van Hemelrijck, and AM Habraken. Quality assessment of speckle patterns for digital image correlation. *Optics and Lasers in Engineering*, 44(11):1132–1145, 2006.

[13] B Pan, Z Lu, and H Xie. Mean intensity gradient: an effective global parameter for quality assessment of the speckle patterns used in digital image correlation. *Optics and Lasers in Engineering*, 48(4):469–477, 2010.

[14] T Hua, H Xie, S Wang, Z Hu, P Chen, and Q Zhang. Evaluation of the quality of a speckle pattern in the digital image correlation method by mean subset fluctuation. *Optics & Laser Technology*, 43(1):9–13, 2011.

[15] S Bossuyt. Optimized patterns for digital image correlation. *Imaging Methods for Novel Materials and Challenging Applications*, 3:239–248, 2013.

[16] G Stoilov, V Kavardzhikov, and D Pashkouleva. A comparative study of random patterns for digital image correlation. *Journal of Theoretical and Applied Mechanics*, 42(2):55–66, 2012.

[17] G Crammond, SW Boyd, and JM Dulieu-Barton. Speckle pattern quality assessment for digital image correlation. *Optics and Lasers in Engineering*, 51(12):1368–1378, 2013.